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IMAGE PROCESSING AND ANALYSIS TECHNIQUES FOR READING

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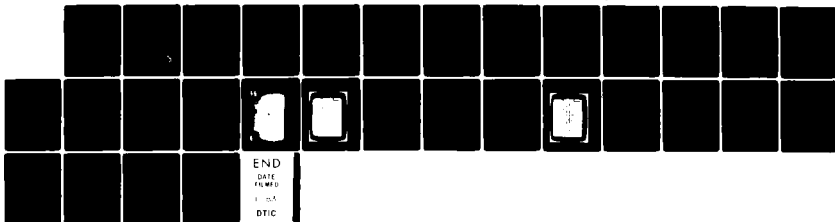
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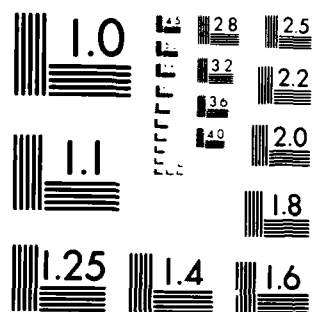
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ROYAL AIRCRAFT ESTABLISHMENT

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Technical Report 82069

June 1982

**IMAGE PROCESSING AND ANALYSIS
TECHNIQUES FOR READING
KINETHEODOLITE FILM SCALES**

by

Ann M. Bagot

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Received for printing 24 June 1982

IMAGE PROCESSING AND ANALYSIS TECHNIQUES FOR READING
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Ann M. Bagot

SUMMARY

This Report describes a series of techniques for processing and analysing images. Although developed for a specific purpose, namely the automatic reading of angular information on Askania kinetheodolite film, most of the techniques are quite general, and potentially applicable to a wide variety of problems. The processes described include real time binarisation of a television signal, production and analysis of projections to determine the positions of features of interest, and character recognition.

Departmental Reference: IT 179

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1 INTRODUCTION

This Report describes image processing and analysis techniques developed as part of a study of the feasibility of automatically reading Askania kinetheodolite film. The problem is described in the following paragraphs and the Report then follows the sequence of processes required for its solution. The description concentrates on the principles of the techniques as these are potentially applicable to a wide variety of problems: a great deal of detail which is specific to the application has been omitted.

The kinetheodolite is essentially a camera on a tracking mount. Fig 1 shows a typical frame of film. The angle at which the instrument is pointing is shown, in elevation and azimuth, in the two areas at the top corners of the frame. It is the reading of the information in these areas which this report describes.

Fig 2 shows an enlarged picture of the azimuth scale. The large digits give the whole number of degrees: they can appear anywhere across the width of the picture in either of two vertical positions, below the centre, as shown, or above. Moving with the digits is a cursor whose position is read against the scale, the length of which is equivalent to 0.5° . If the main digits are above the scale, the reading is in the range $x.0^\circ$ to $x.5^\circ$, if below, the reading is in the range $x.5^\circ$ to $x + 1^\circ$. Interpolation to 1/10 of the scale graduations gives a resolution in the reading of 0.001° . Thus the scale in Fig 2 is showing a reading of 158.719.

It was required to read this information in less than 1 second.

Physically, the equipment used to do this comprises a television camera, specially designed analogue and digital electronics, and a PDP LSI-11 mini computer. Many of the processes were implemented in hardware because of the speed requirement, with the computer being used for final analysis and control. Fig 3 shows a block diagram of the major components of the system. Solid lines indicate the flow of information, and the dashed lines show control links between the computer and other components of the system. Fig 4 is a flow diagram of the scale reading process: the Report describes the techniques used in the order indicated by this Figure.

Although the picture contains many shades of grey, in essence it is two-tone: black and white. The first process required, therefore, is the conversion of the video signal produced by the camera into a two-level signal. This significantly reduces the amount of information involved in, and the complexity of, the remainder of the processing. A simple thresholding method would not be adequate for the binariser: the reasons for this, and the technique which was developed, are described in section 2.

The two-level picture is produced in real time with a delay of 2 μ s relative to the grey scale video. The binary signal is sampled to give 1024 one-bit samples along each television scan line. This data rate is too high to be read directly by the computer, so a special memory was built. This video memory, which is capable of storing up to 64 lines of the binarised, sampled television signal, is described in section 3. Techniques for 'projecting' part of the picture on to the horizontal or vertical axis have been developed. These are implemented in hardware and the results are analysed in the computer to give information about the positions of features in the picture, including that of the cursor relative to the scale lines. The production and analysis of the projections are also described in section 3.

Following the analysis of the projections, the position of each of the large digits is known. Before being passed to the character recognition stage, each digit is scaled down to a standard size. Section 4 describes the scaling process. Section 5 then describes the weighted mask matching method used for character recognition. In order to optimise the mask weights, and also to enable the extension of the system to other character sets, an automatic mask generation technique was developed, and this is outlined in the second part of section 5.

2 THE BINARISER

The information in the film scale area is contained in a pattern of white lines on a black background. Reducing the video signal to this two-level pattern has several advantages over processing the full range of grey levels. By removing variations between scales, which carry no useful information, it produces a more standard input for further processing; it reduces the size of video memory required; and, following from these two factors, it reduces the complexity and therefore increases the speed, of the subsequent processing, particularly that done by the hardware.

For many reasons, the image on the film is highly variable. Factors which vary include:

- the density of 'black' and 'white'
- differences between main digit 'white' and scale line 'white'
- contrast
- shading, that is, the density of 'black' varies from one side of the picture to another, sometimes by an amount comparable to the difference between white and black at any given point
- noise, that is, unwanted items in the picture such as dirt or, in the case of very 'thin' film, the grain of the film.

These properties are fairly constant along a given film, so the following setting up procedure, performed for the first frame of each film, is used to reduce some of the variations between films before the video signal is passed through the binariser. First, the position of a variable density filter, placed in front of the television camera, is automatically varied until the 'white' part of the signal reaches a predetermined threshold. The signal bias is then adjusted so that 'black' is at a defined level. Finally, if the dynamic range of the signal is less than half, or even quarter, of the maximum allowed, then the video signal is electronically amplified by a factor of two or four respectively. When setting up the white and black levels, the signal is only tested over a given, computer controlled, area so that the features of interest can be optimised. For example, the 'white' surrounding the scale is much whiter than the lines on the scale and is allowed to saturate in order to optimise the setting up for the scale. Further, as protection against small noise features, the detected maxima and minima must last for a minimum total length of time (accumulated anywhere in the control area) or they are ignored.

These processes reduce some of the film variability problems, but noise, shading and different levels of white remain. The effects of these are too great to allow the use of the simplest binarising technique, namely comparing the signal with a fixed global threshold. A variable threshold must be used, the value of which depends on the local nature of the picture. In other words, the picture must be analysed by comparing each point with its neighbours. Several techniques for generating local thresholds are described in Refs 1 and 2. Most of these techniques require consideration of an area surrounding a given point and are therefore slow. In order to produce the binarised signal in real

time, the process described here considers only the neighbouring points in the same television scan line. However, as most of the features of interest consist mainly of vertical lines, this restriction does not cause serious degradation.

Fig 5 illustrates the basic principles of the binarising process. The upper part of the Figure shows a block diagram of the stages of processing the television signal, and the lower part shows the waveforms produced at the labelled points as the camera scans across a vertical white line.

The video signal is passed down a tapped delay line: the signal to be binarised is that which is present at the centre tap (this is the CENTRE signal, labelled A in the Figure). Signals present at the other taps on the line represent the television picture during the 2 μ s preceding, and the 2 μ s succeeding, the centre. The maximum and minimum values of the signals at all the taps are detected continuously (yielding waveforms B and C) and the average of the maximum and minimum is taken (D). The CENTRE signal value is compared with this average. If both black and white signals are present within the delay line, the difference between CENTRE and average will be substantial, except for the brief periods of transition of A from black to white and vice versa, thus allowing a reliable decision as to whether the centre is black or white. This is shown by the central portion of signal F in Fig 5. If, however, the signal in the delay line is all black or all white, then minimum, maximum, average and centre are approximately the same, and the result of the comparison depends on small, random, picture variations, producing 'speckle' as at the ends of signal F. This speckle is suppressed by making use of the knowledge that the picture comprises white lines on a dark background, implying that a substantially constant signal is always black. The detected minimum, C, is adjusted so that it slightly exceeds the peak of the 'noise' signal (see below). This shifted signal is E in Fig 5. Whenever E is greater than the detected maximum B, the binary video output is set to the black level. This is done, as shown in Fig 5, by interpreting the result (waveform G) of comparing the maximum and shifted minimum as a 'permit' signal which is combined with F using the logical 'and' function to produce the binary video.

The adjusted minimum level is set manually via the computer to give an optimum picture. Originally it was intended to monitor the noise signal and allow the computer to determine the appropriate adjustment, but this has not been implemented. Because the noise characteristics of a particular film do

not vary significantly from frame to frame, the determination of the shift is generally required only once per film.

In order to minimise the effect of shading across the film, the delay time should be short. It was chosen to be approximately the same as the spacing of the scale lines so that when binarising the scale some white and some black are always present. However, this is not satisfactory for horizontal white lines such as the top of a main digit '7' because in the middle the delay line contains only white signal which, as described above, leads to a black output from the binariser. To overcome this, the computer can select a longer delay when analysing main digits. This spans the width of the main digits and fills in the horizontal lines, but is much less resistant to shading.

Around the scale area is a wide white border which, under the system described above would be output as black except for narrow bands at the edges of the scale area. To ease the process of finding the scale area boundaries, it is desirable that the border be white. This is accomplished by an additional function, not shown in Fig 5, which takes advantage of the fact that the border is much whiter than the scale features. The white level defined for setting up the variable density filter position is used as a threshold and any signal outside the control area which exceeds this is set to white.

Fig 6 shows the binarised version of Fig 2.

3 THE VIDEO MEMORY, PROJECTIONS AND THEIR ANALYSIS

3.1 The video memory

The two level video signal is sampled at a rate which produces 1024 samples along each television scan line. A special digital memory has been built to receive this data. In it can be stored a block of up to 64 lines starting anywhere in the picture. The computer specifies the first and last lines required and then instructs the memory to acquire the information. The hardware waits until a new scan of the picture starts and thus reads all the data lines from the same scan.

The process of data acquisition is illustrated in Fig 7 which shows a part of the video memory capable of storing 16 scan lines. The complete memory comprises four such bands. In order to obtain 1024 samples along each scan line, the video signal is sampled at 19 MHz. The video memory is not capable of accepting the single-bit samples at this rate, so they are first formed into

16-bit words by a serial-to-parallel converter, giving a word rate of 19/16 MHz. Fig 7 shows the positions in which the first few samples from the first three and the sixteenth scan lines are stored. This arrangement is necessary to enable the data to be read in at the required rate, but is inconvenient for further processing. After all the data has been captured, a 'reorientation' process is performed which re-writes the data into the more convenient form shown in the lower part of the Figure.

It is possible to access the contents of the video memory (both to read and write) from the computer. This facility is, however, only used to test memory function. For scale reading the data goes through further processing by the hardware before being passed to the computer.

3.2 X and Y projections

Although the general format of the scale area is constant, the positions of the various features are not fixed and must be determined for each scale. This applies even to the boundaries of the scale area whose positions relative to the television camera can move: the vertical position changes from film to film, and the horizontal position varies as the film is carried through its holder or transport. Feature positions are determined by analysing projections of different areas of the picture. This section defines X and Y projections and describes their production by the hardware.

The binary picture can be thought of as a matrix of elements $a(i,j)$ which can take only two values, 0 or 1. Any rectangular area in the picture is a submatrix restricted by limits such as $r \leq i \leq s$ and $t \leq j \leq u$. The projections of this submatrix on to the horizontal (X) and vertical (Y) axes are defined to be:

$$PX(i) = \sum_{j=t}^u a(i,j) \quad \text{for } r \leq i \leq s$$

and

$$PY(j) = \sum_{i=r}^s a(i,j) \quad \text{for } t \leq j \leq u$$

respectively.

The Y-projection is produced on a line-by-line basis directly from the sampled binary video signal. The computer specifies the area of interest and, for each required line, the hardware accumulates the number of ones between the first and last elements specified. This total can then be read by the computer. This must be done before the next line's total is available: the hardware detects failure to do this and causes the computer program to be interrupted.

The X-projection is produced from data in the video memory (and the area covered is therefore a maximum of 64 lines high). The function is an integral part of the video memory structure. There are four mask registers of 16 bits each with each bit corresponding to a line of the video memory. The computer can write values into the registers with a '1' in each position corresponding to a line to be included in the projection. The computer also outputs the first column number of interest. When the X-projection value is then requested, a logical 'and' function is performed, bit by bit, on the mask registers and the data column, and the resulting accumulated number of ones is returned to the program. The column number can automatically be either incremented or decremented, if required, so that the computer can simply read in consecutive projection totals.

3.3 Projection analysis for feature position detection

The computer program specifies and analyses a sequence of projections in order to determine the positions of the various features in the picture, including the position of the cursor along the scale. Figs 8 to 11 illustrate this process: they are all projections of parts of Fig 6. Ref 3 describes another example of the use of projection analysis.

In general, where boundaries are clear, simple threshold crossing is used to determine their positions. Where the boundaries are less obvious, for example because the features may overlap or because noise may be significant, then the analysis routines search for local maxima and minima to determine positions.

First the boundaries of the scale area are required. Fig 8 shows the X-projection of a band of 64 lines across the whole width of the picture, approximately in the centre. The positions of the left and right edges are obvious. These edges then define the first and last columns required for the

Y-projection of the whole height of the picture, shown in Fig 9. The top of the picture is at the left of the Figure. Again, the positions of the top and bottom edges are clear. Between the top and bottom edges, the most prominent features are the peaks produced by the scale lines. The two maxima are found, then the local minima which define the top and bottom of the upper and lower sets of lines respectively. The gap between the two sets of lines in which the cursor appears is known to be only seven lines high. Because the gap is so narrow, its projection is easily distorted by noise, or by slight misalignment between the film and television scan horizontals, so its position is taken to be that of the seven smallest values between the peaks.

The remaining information required from this projection is the position of the main scale digits. They can be in one of two bands, the upper one of which is considered first. The total white in the band, that is, the sum of all the projection values, is compared with a threshold to determine whether or not digits are present. In the current example, the upper main digit band is almost entirely black, so the program proceeds to consider the lower band. Having decided that digits are present, their precise boundaries are determined by thresholding.

Following this analysis of the Y-projection, the area containing both the top set of scale lines and the cursor is read into the video memory. Fig 10a shows the X-projection of the cursor band. Apart from some noise, the cursor is the only feature present and is readily detectable. In order to calculate the scale reading, the position of the centre of the cursor must be estimated: the position which most closely balances the sum of cursor projection values to its left and right is used.

Fig 10b shows the X-projection of the upper set of scale lines. The simplest way to calculate the scale reading would be to interpolate the cursor position between the first and last lines. However, the error in the scan linearity of the television camera may be up to 2% of the picture width and could cause significant error in this calculation. To overcome this, the scale lines are counted (both before and after the cursor, as a check) and interpolation of the cursor position is just between those lines closest to it.

Finally, the band containing the main scale digits is read into the video memory. From its X-projection, shown in Fig 11, the horizontal positioning of the digits can be determined.

Thus, at this stage, the fractional part of the scale reading has been determined, and each main digit is stored in a known area of the video memory ready to be passed to the final processing stages.

4 SCALING

The main scale digits as they are stored in the video memory are not immediately suitable as input for character recognition. Firstly, they are too big, being typically about 65 columns wide by about 40 lines high. (Resolution is much greater horizontally than vertically.) Secondly, the size is not constant for various reasons including changes in optical magnification (at both kinetheodolite and television camera) and 'noise' in the binarising process. Thus it is necessary to scale the digits down to a suitable size. This was chosen to be 10 columns by 20 rows which reflects the actual aspect ratio of the digits on the film and gives a nominal line width of one element.

The scaling process is illustrated in Fig 12.

If the digit is, say, N elements wide, it can be divided into x columns of width A and $(10 - x)$ columns of width $(A + 1)$ where A is the integer part of $N/10$, and $(10 - x)$ is the remainder. For example:

$$N = 66 \quad \text{gives} \quad A = 6 \quad \text{and} \quad x = 4.$$

So 66 elements can be divided into four columns of width 6 and six columns of width 7. Similarly, the height can be divided into 20 parts.

From its knowledge of the boundaries of the digit, the software calculates 'A' and 'x'. The pattern in which the groups of size A and $A + 1$ are distributed is predetermined for each possible value of x . The information is stored in a table in computer memory in the form of bit patterns where '0' corresponds to group size A and '1' corresponds to group size $A + 1$. The patterns were chosen to distribute the different sized groups as evenly as possible.

The scaling process is carried out by special hardware, under firmware control. For both the horizontal and vertical directions, the software outputs the starting point in the video memory, the pattern, and the smaller group size (ie 'A'). The grouping process described above divides the digit into rectangles of, in any particular instance, four possible sizes, as shown in Fig 12.

If $S(i)$, $i = 1, 2, 3, 4$ are the rectangle sizes, the software calculates the four values $S(i) \times N / 100$ (where N is a constant, at present equal to 50), rounded to the nearest integer, and sends them out as threshold values. The hardware, using the patterns, knows the size of each rectangle. It counts the number of ones present and compares the total with the given threshold for the particular rectangle size in order to decide whether the scale digit element should be '0' or '1'.

The 10×20 scaled digit array is stored in a special memory in the hardware. The data is available to the computer for testing purposes, but is normally read directly by the character recognition hardware.

5 CHARACTER RECOGNITION AND MASK GENERATION

5.1 Character recognition

The main scale digits are recognised using the process of correlation with weighted masks. The principles of this technique are illustrated in Fig 13, and it is explained briefly below. Ref 2 describes this and other character recognition techniques: this one was chosen because of the possibility of automating the design of the masks. Ref 4 describes another implementation of this technique.

If binarised and scaled samples of a particular numeral were always identical, then a very simple mask matching technique would always produce correct recognition: a sample of each digit would be stored, and each unknown would be compared with all the samples. In the ideal situation there would be one perfect match. In practice, however, 'noise' of various types is introduced at each of the processing stages involved in producing the binarised, scaled digit resulting in wide variations such as those between the unknown digit and the simple '5' mask illustrated in Fig 13. Simple matching in this case results in the central '5' being recognised as a '6'. There are only three small areas of difference between a '5' and a '6' of this sort of design and these are indicated by '+' and '-' symbols in Fig 13. If these are given more importance, say by giving them ten times the 'weight' per element, then as shown by the sums of products, S , in the right-hand part of Fig 13, the '5' is correctly recognised.

It is easy to design, by eye, weighted masks to distinguish between two digits. Extending this principle to distinguish between 10 digits simultaneously is much more difficult and requires the use of a range of weight values.

The computer program which was written to generate the weighted masks is described in section 5.2.

The mask values are stored in a special memory in the hardware. On command from the computer, the contents of the scaled data memory are passed to the character recognition hardware which calculates the 10 correlation values. The arithmetic for the 10 masks is done in parallel and the process is therefore very fast. The totals are read into the computer and normalised (see the following section). The software then decides, on the basis of their absolute and relative values, which digit, if any, is contained in the scaled data memory. Having found the largest total, the program checks that it is both greater than a certain fixed threshold and that the difference between it and the second largest total is greater than another threshold amount before accepting that the corresponding digit is indeed present. Varying these thresholds alters the balance between the number of misread samples and the number of samples rejected as unreadable.

5.2 Automatic mask generation

A process for automatically designing weighted character recognition masks was developed partly because of the complexity of simultaneously differentiating between 10 digits, and partly in anticipation of a requirement to recognise other digit fonts.

Several samples of each digit were collected to provide design data for the process. For each digit, the samples were added together and normalised to give a composite representation with values in the range -10 to +10. The process designs one weighted mask at a time. Let the elements of this be $m(i)$, the elements of the composite digit to which it corresponds be $a(i)$, and the elements of the remaining composite digits be $b(j,i)$, where $1 \leq i \leq 200$ and $1 \leq j \leq 9$.

Let TA be the correlation total of the mask with the composite digit for which it is being designed, ie

$$TA = \sum_{i=1}^{200} a(i)m(i)$$

and let $TB(j)$ be the correlation total of the mask with the j th composite digit, ie

$$TB(j) = \sum_{i=1}^{200} b(j,i)m(i) \quad .$$

It is required that TA shall be significantly greater than all the $TB(j)$. This will be so if the ratios $TB(j)/TA$ are small, and the design task can therefore be defined as choosing the $m(i)$, within a fixed range of values, such that the nine ratios are minimised simultaneously.

Initially, the $m(i)$ are set equal to the $a(i)$. The following process is then repeatedly performed.

The nine correlation ratios are calculated and the maximum is determined. For this maximum, a digital, approximate, differentiation is used to find the $m(i)$ to which the ratio is most sensitive, and whether it should be increased or decreased in order to reduce the value of the ratio. The $m(i)$ is then changed by $+1$ or -1 , as appropriate, provided both that the new value is still within the allowed range and that this change would not increase any of the other eight ratios. If the most sensitive $m(i)$ cannot be changed, then the next one is found, and so on until a change is made, at which point the whole process is repeated.

If no change can be made the process terminates. In practice, before this point is reached all the ratios become less than zero, and this also terminates the process. The final value of TA for each digit is used to normalise the totals produced by the character recognition hardware, as described previously.

6 CONCLUSIONS

This Report describes briefly several image processing and analysis techniques which have been developed for a specific application but which are potentially applicable to a wide variety of problems. The implementation of these techniques using the combination of hardware and software described in the Report is capable of reading the information in an Askania kinetheodolite film scale area in less than 1 second.

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Fig 1



Fig 1 Frame of Askania kinetheodolite film

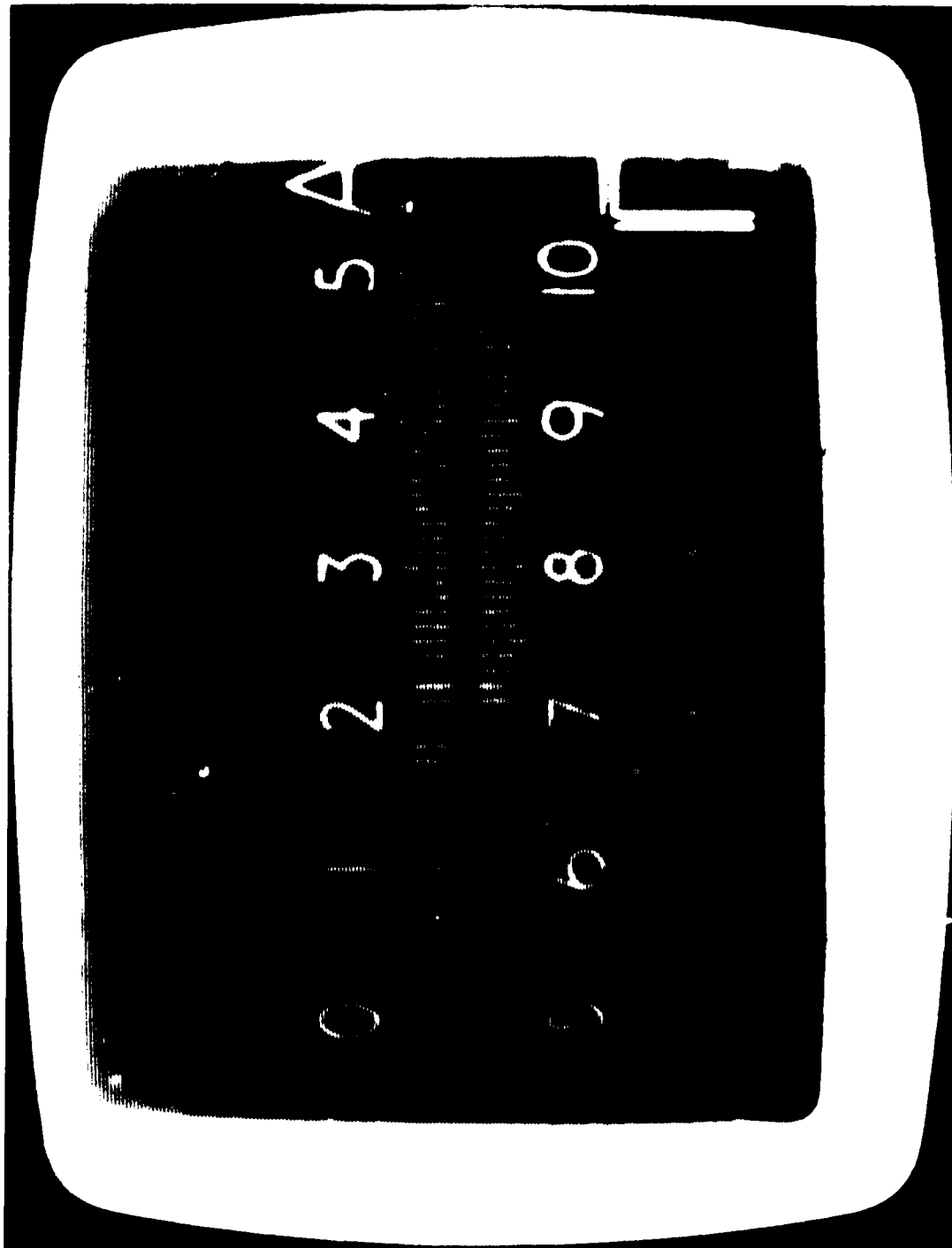


Fig 2

Fig 2 Television picture of azimuth scale

Fig 3

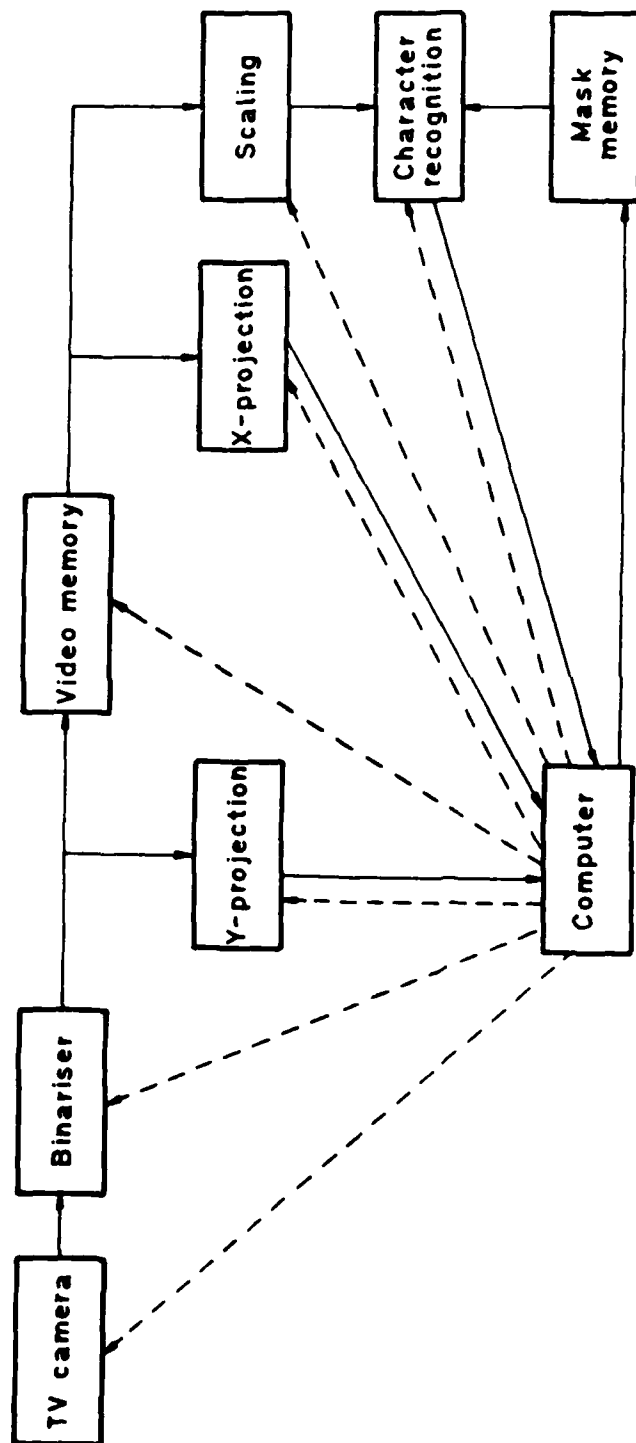


Fig 3 System block diagram

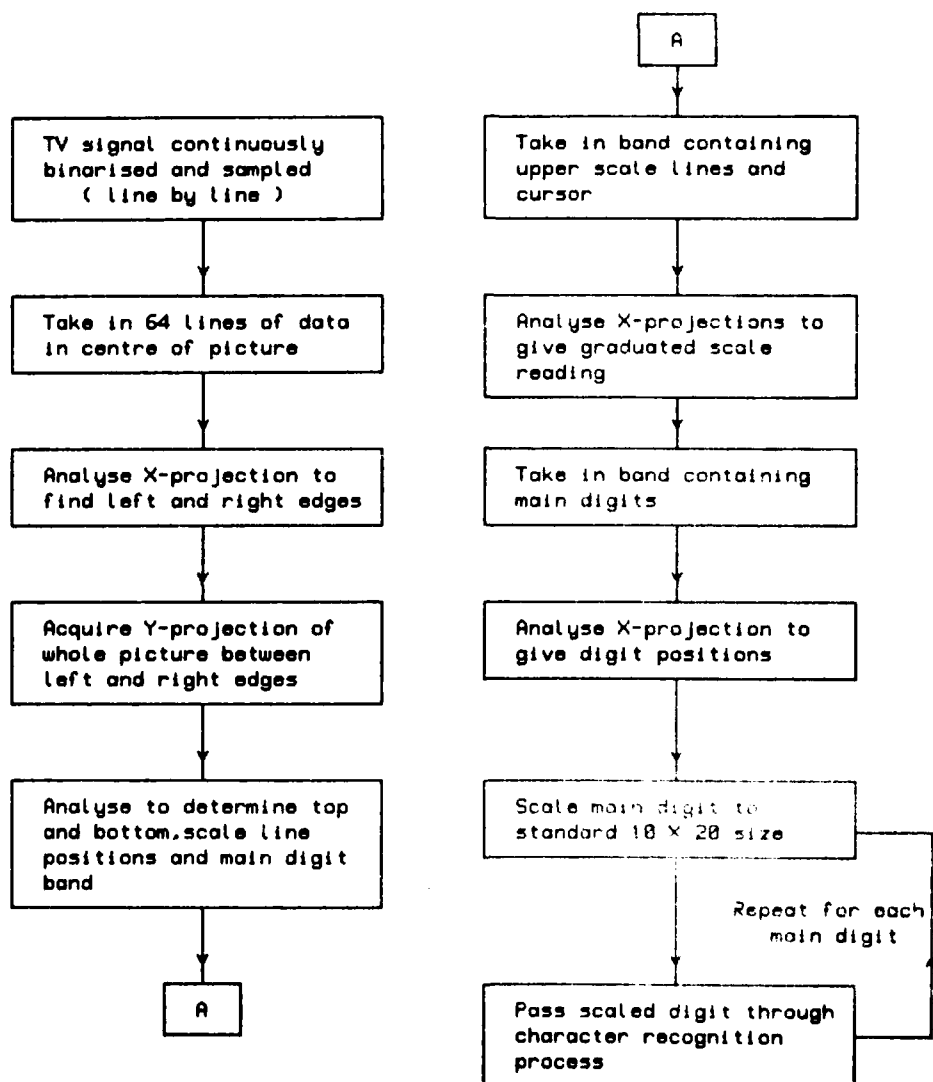


Fig 4 Flow diagram of scale reading process

Fig 5

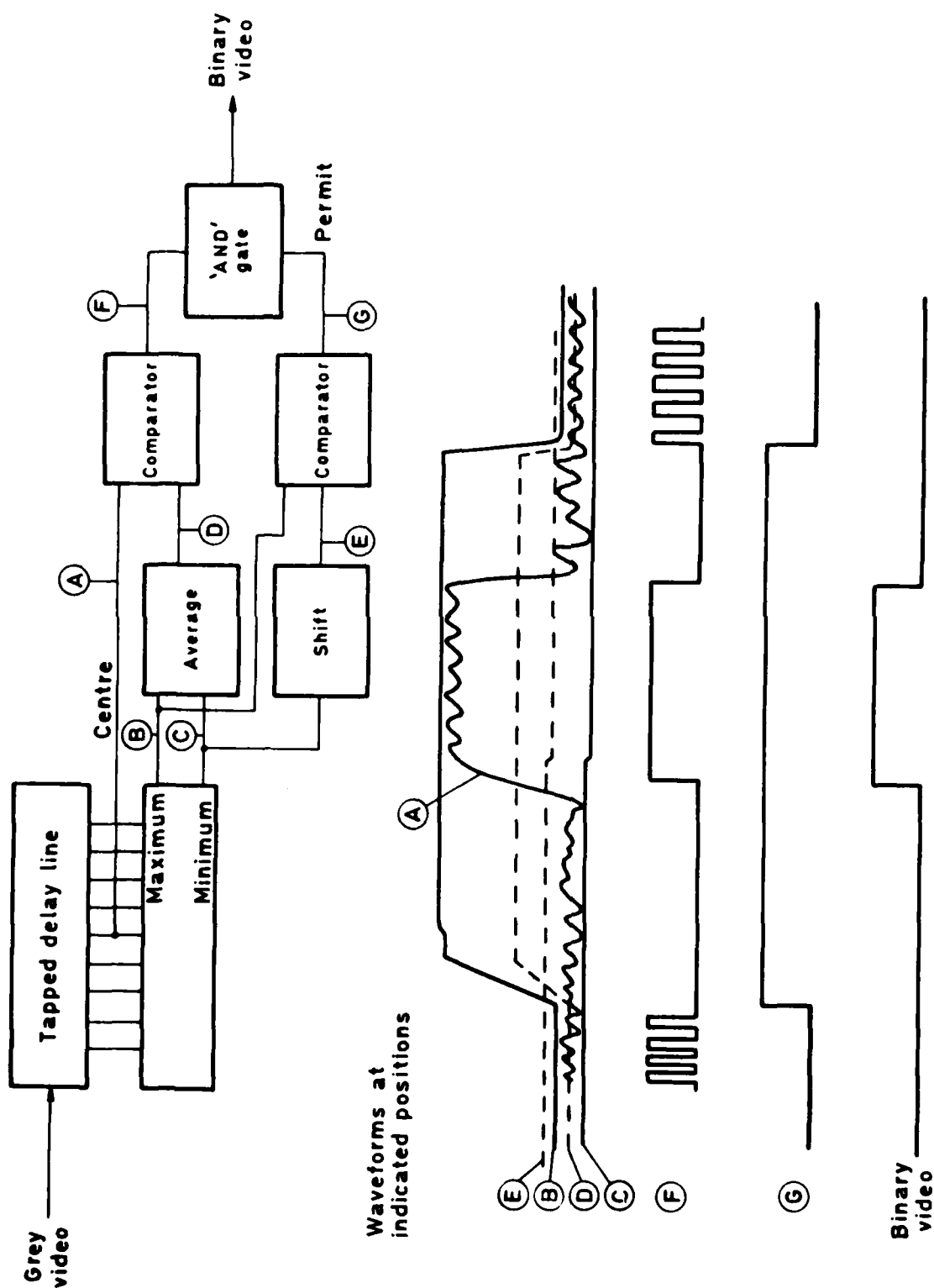


Fig 5 Principle of the video binary converter

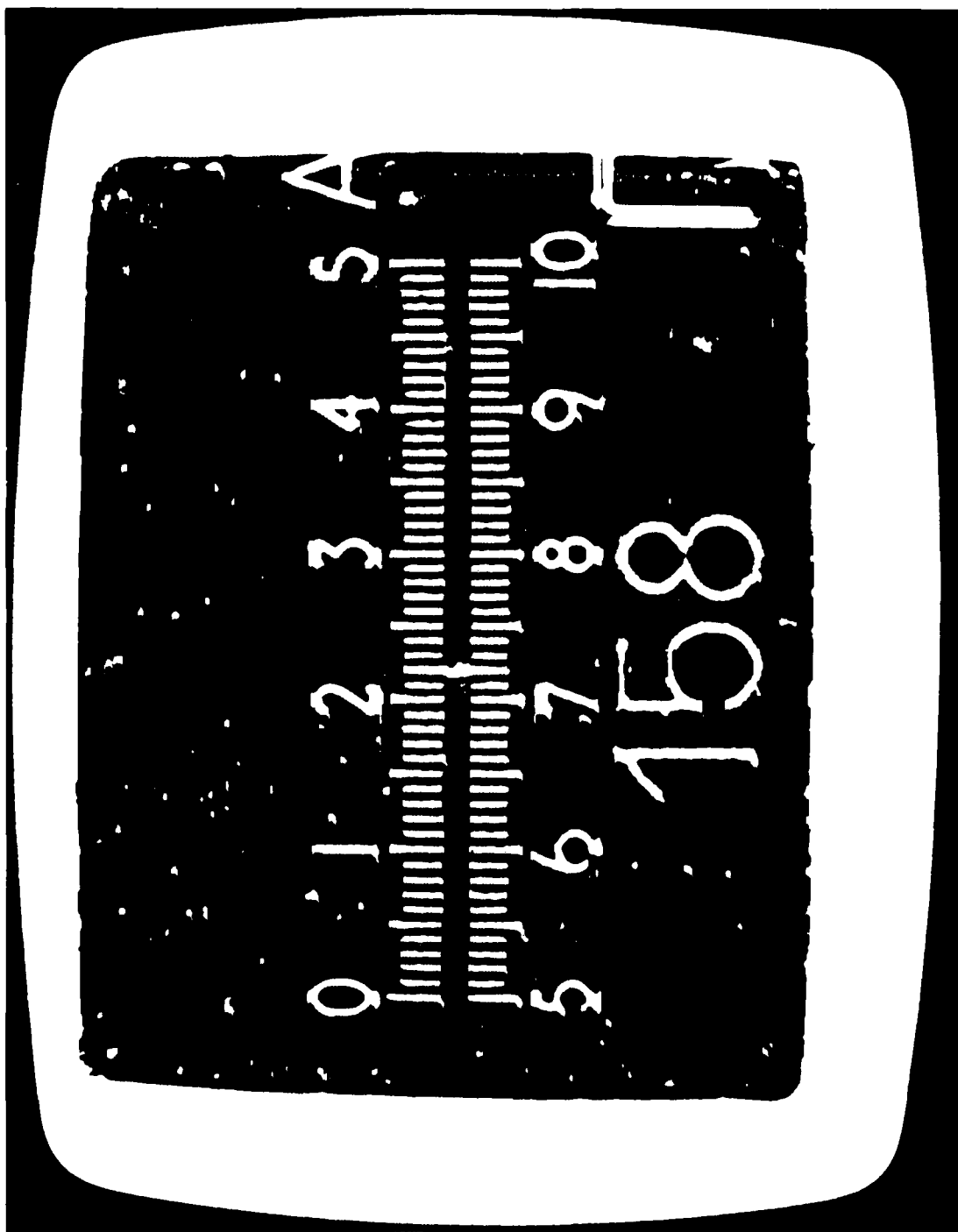


Fig 6

Fig 6 Binarised television picture of azimuth scale

Fig 7

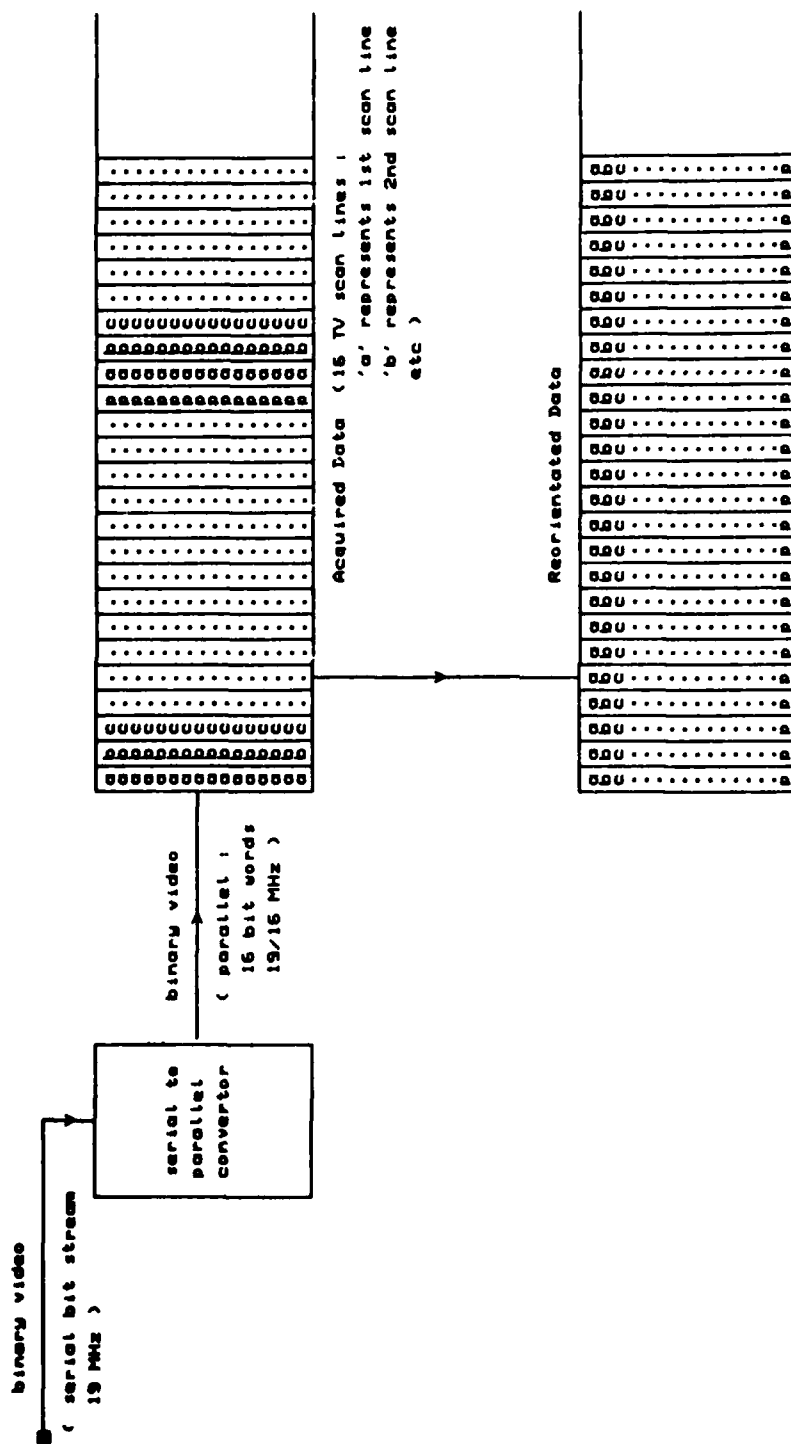


Fig 7 Principles of video memory function

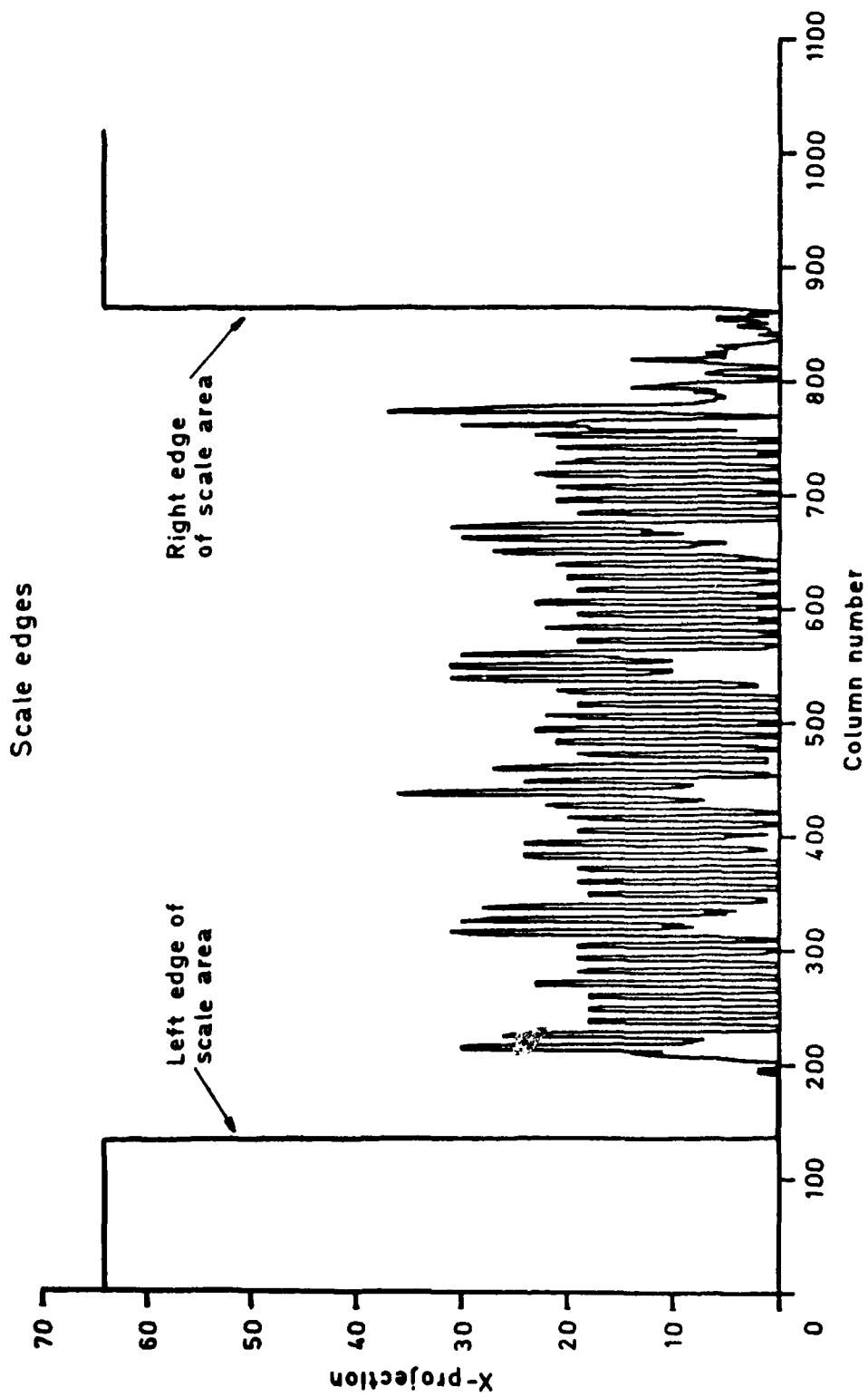


Fig 8 X-projection of central band of the scale

Fig 9

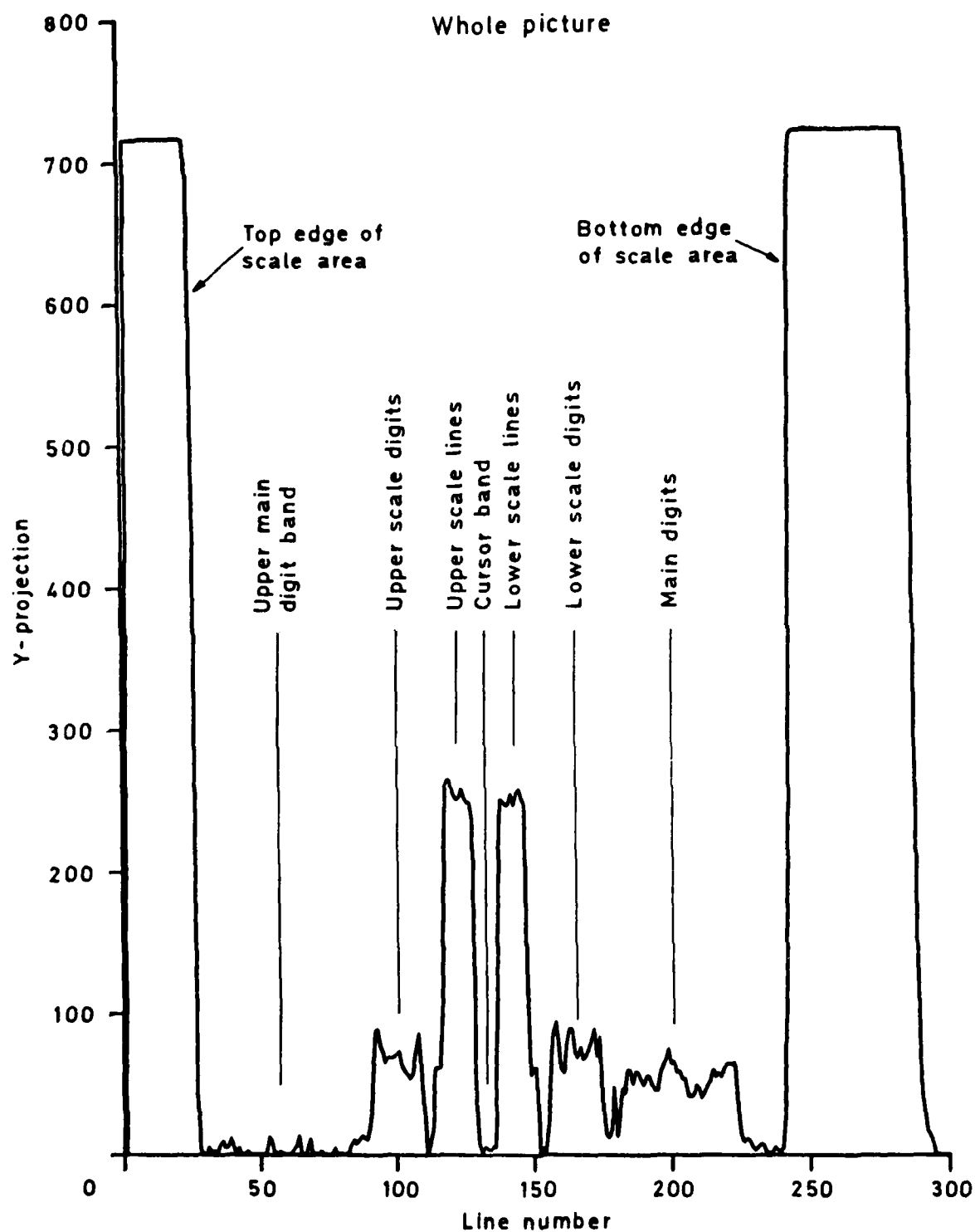


Fig 9 Y-projection of whole picture height

Fig 10a&b

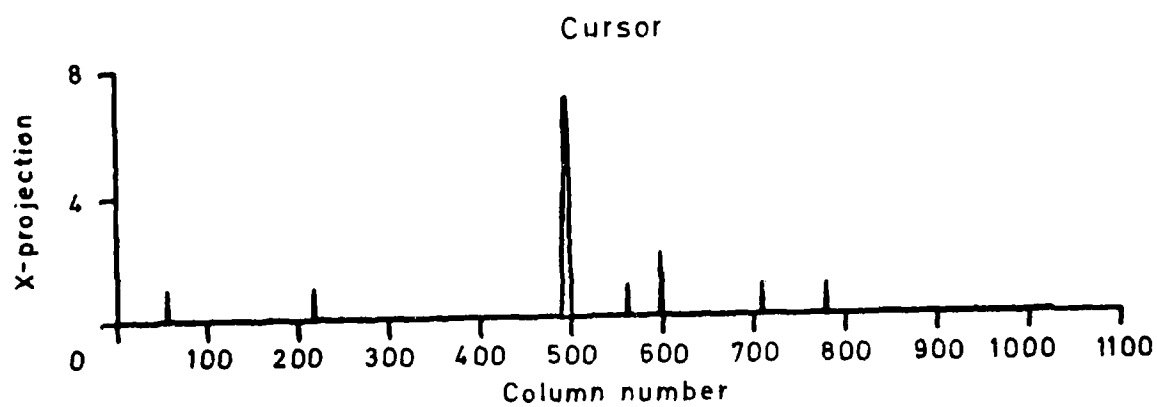


Fig 10a X-protection of cursor band

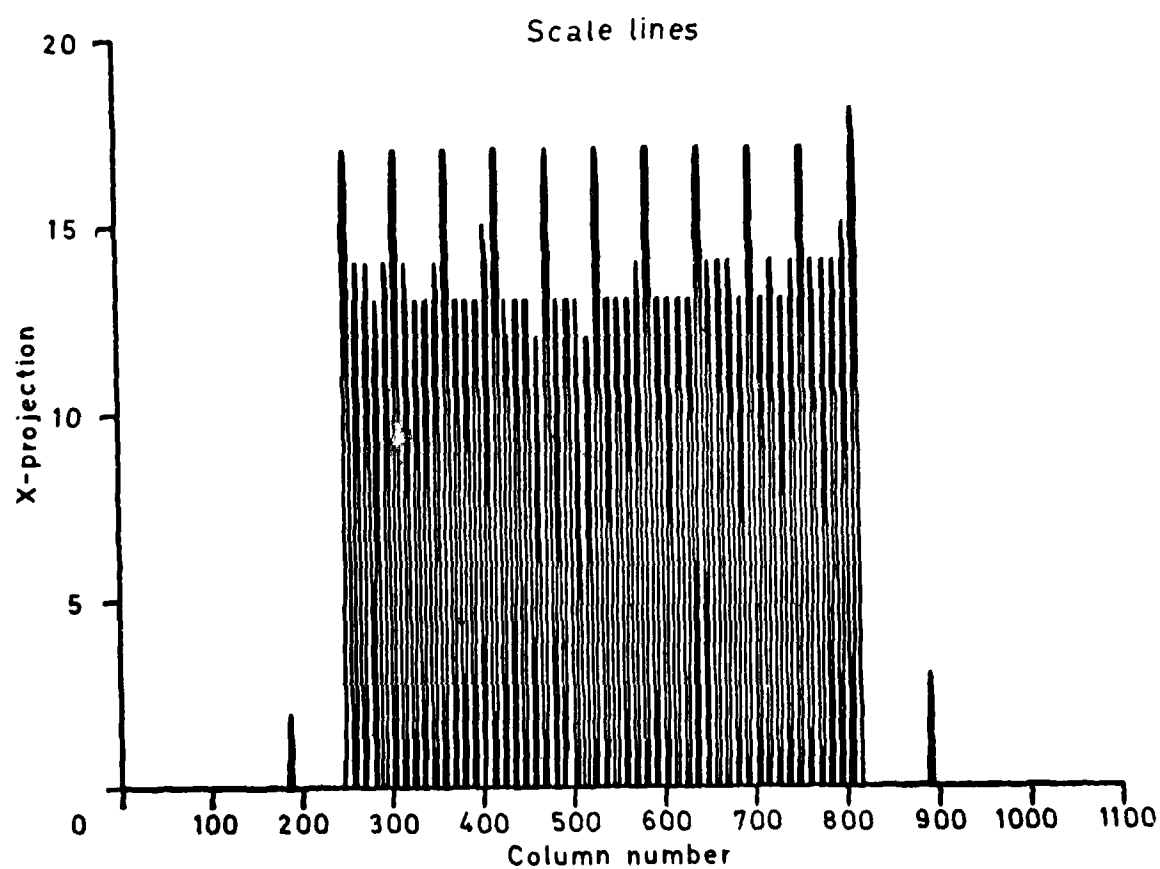


Fig 10b X-projection of scale lines

Fig 11

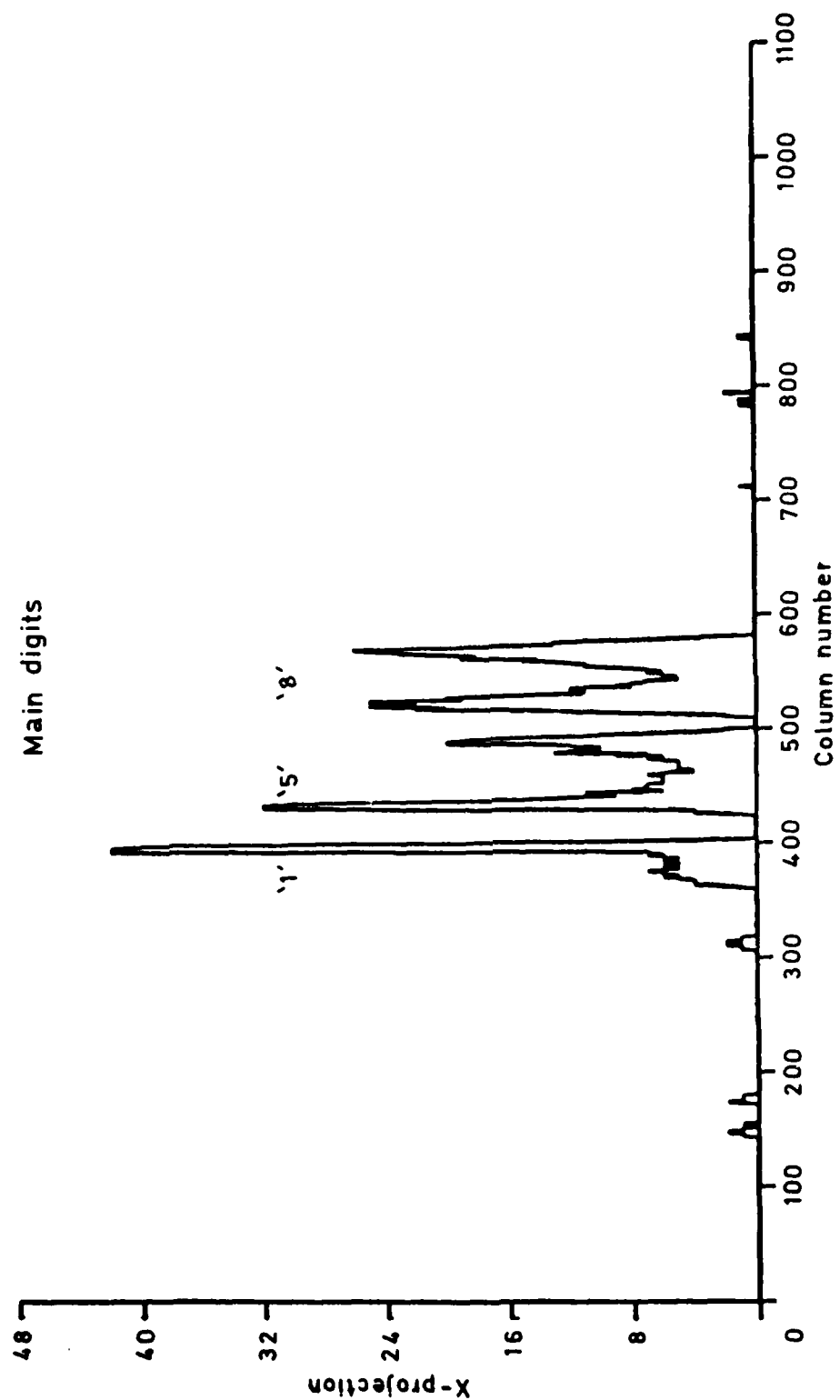


Fig 11 X-projection of main digit band

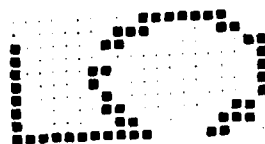
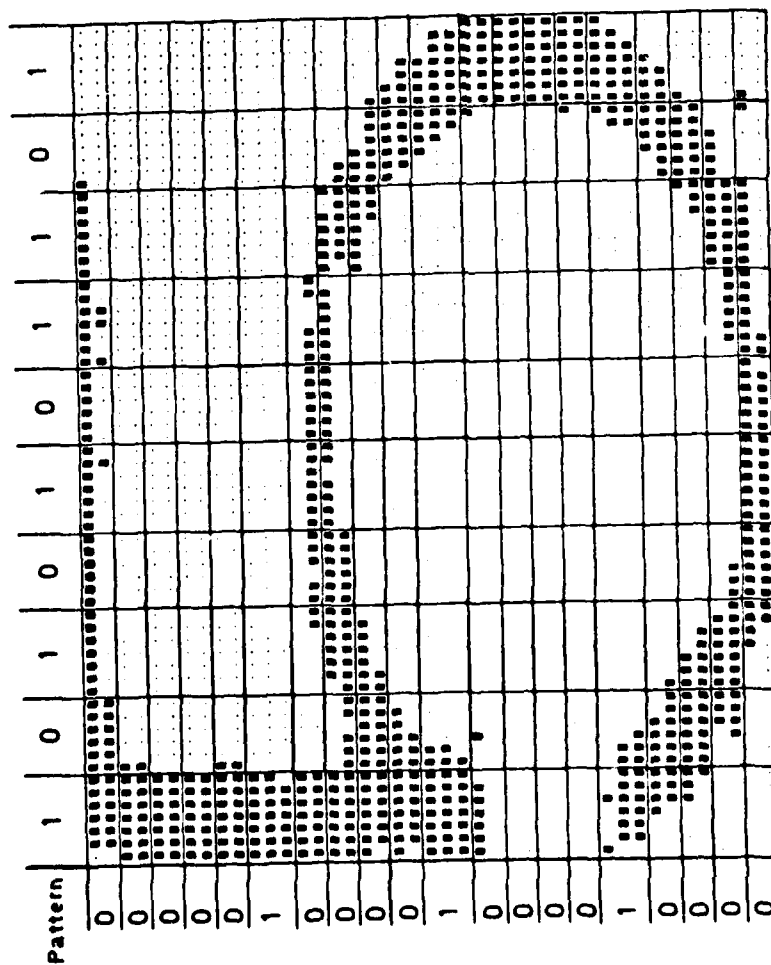


Fig 12

Fig 12 The scaling process

Fig 13

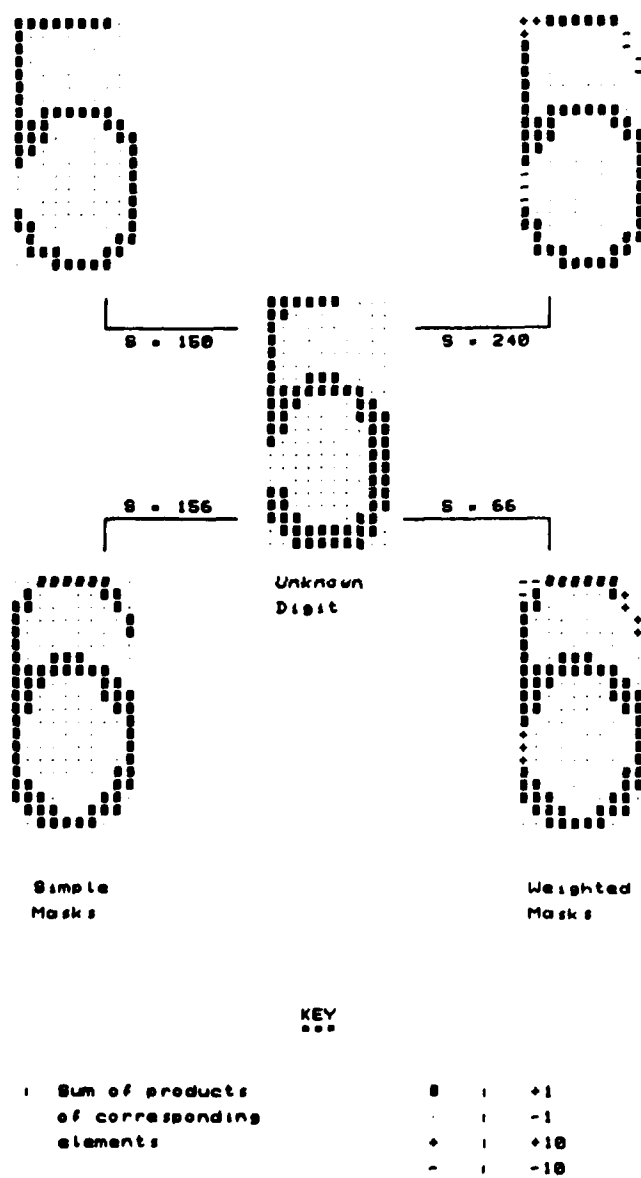


Fig 13 Principles of weighted mask character recognition

REPORT DOCUMENTATION PAGE

Overall security classification of this page

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1. DRIC Reference (to be added by DRIC)	2. Originator's Reference RAE TR 82069	3. Agency Reference N/A	4. Report Security Classification/Marking UNCLASSIFIED		
5. DRIC Code for Originator 7673000W		6. Originator (Corporate Author) Name and Location Royal Aircraft Establishment, Farnborough, Hants, UK			
5a. Sponsoring Agency's Code N/A		6a. Sponsoring Agency (Contract Authority) Name and Location N/A			
7. Title Image processing and analysis techniques for reading kinetheodolite film scales					
7a. (For Translations) Title in Foreign Language					
7b. (For Conference Papers) Title, Place and Date of Conference					
8. Author 1. Surname, Initials Bagot, Ann M.	9a. Author 2	9b. Authors 3, 4	10. Date June 1982	Pages 28	Refs. 4
11. Contract Number N/A	12. Period N/A	13. Project	14. Other Reference Nos. IT 179		
15. Distribution statement (a) Controlled by — Head, Instrumentation & Trials Dept, RAE (b) Special limitations (if any) —					
16. Descriptors (Keywords) (Descriptors marked * are selected from TEST) Image processing. Image analysis. Character recognition.					
17. Abstract This Report describes a series of techniques for processing and analysing images. Although developed for a specific purpose, namely the automatic reading of angular information on Askania kinetheodolite film, most of the techniques are quite general, and potentially applicable to a wide variety of problems. The processes described include real time binarisation of a television signal, production and analysis of projections to determine the positions of features of interest, and character recognition.					

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